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Risk Level Problems Affecting Microtunneling Projects Installation

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Affecting Microtunneling Projects Installation

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Risk Level Problems Affecting Microtunneling Projects Installation

Abstract

Microtunneling is a complex trenchless excavation process. Efficient microtunneling methods is necessary to identify risk level problems that often require the integration of supporting equipment and personnel. A clearer understanding of risk level problems will facilitate the enhancement and modeling of risk assessments for future microtunneling projects. This study investigates twelve different factors to assess risk level problems in microtunneling projects. The factors and factors' weight are collected using a questionnaire sent to microtunneling-industry specialists. A risk level prediction model is developed using the clustering analysis technique and the Analytical Hierarchy Process (AHP) to consider the qualitative factors involved in the microtunneling process. The model is then validated, which shows reasonable results with 89% Average Validity Percent. The main objective of the developed model is to assist contractors in the bidding and operation phases of microtunneling projects by providing reasonably accurate mitigation models.

Keywords: Microtunneling, Risk Level, Trenchless Technology, Clustering Analysis, AHP

Introduction

Trenchless Technology is a special tunneling technique that can be defined as “Environmental sound technologies” (EST) which is used in the installation of new pipes. This technique is in high demand due to the need for utility line replacement or repairs with minimum disruption to the surface during installation (Hegab and Salem 2010). Trenchless Technology is an environmentally friendly technique that helps in reducing pollutants to the environment,

reserving natural resources, and handling waste. It is “a family of methods, materials, and equipment capable of being used for the installation of new, replacement, or rehabilitation of existing underground infrastructure with minimal disruption to surface traffic, business, and activities” (Hashemi 2008). In addition, Trenchless Technology methods are used for repairing, upgrading or installing underground infrastructure systems to offer less surface disruption compared to open-cut methods (Mohanapriya and Kumar 2015).

The concept of microtunneling can be defined as “a trenchless construction method for installing pipelines with all of the following features utilized: remote-controlled from a control panel on ground surface, laser guided, pipe sections jacked simultaneously as spoil is excavated, and continuous support at the face of the excavation” (ASCE 2001). The main advantage of microtunneling is its capability to install pipes with a low risk of injury and less damage to overall ground settlements, structures and roads in an urban environment (Luo 2007).

The differences between microtunneling and the pipe jacking method can be demonstrated in the diameter of pipe installations. Microtunneling involves pipe installations up to 900 mm in diameter; however, pipe jacking involves pipe installations greater than 900 mm in diameter (PJA, 1995; (Khondoker et al. 2016). In 1890, the pipe jacking method first appeared in the US, which has been defined as the minimal surface disruption pipe installation method (Drennon 1970; Khondoker et al. 2016). In the 1950s, the UK used the pipe jacking method in short-length installations in crowded urban areas, followed by Japan and Germany (Yonan 1993; Khondoker et al. 2016).

However, the definition of microtunneling slightly differs in Europe, Japan, and the United States of America (USA). Europe and Japan define a pipe-jacking machine as a microtunneling machine based on its size. In Japan, any size below 800 metric linear units may be considered a microtunneling machine whereas in Europe the margin is 1000 metric linear units (Thomson 1993). USA contractors define any remotely controlled, guided pipe-jacking machine as a microtunneling machine (Salem and Hegab 2001). In addition, the microtunneling technique is applied in various projects such as gravity and pressure lines, permanent ducts for cables, and crossings beneath railways or roads. Monitoring and controlling the construction productivity of pilot tube microtunneling (PTMT) are important in reducing the delays of tunneling projects and in decreasing project costs (Tang 2015). Many factors affect risk level problems of microtunneling projects installation. The literature review describes these factors are site condition, geological condition, installing geometry, project contract, and trenchless method (Islam et al. 2013).

In spite of an extensive variety of outstanding studies in microtunneling installation projects. Risk level problems have not been applied more often to microtunneling projects installation (Ali et al. 2007; Hegab and Salem 2010 ; Marzouk et al. 2010; Hegab and Smith 2007; Chung et al. 2004; Zayed and Mahmoud 2013)

This paper presents findings from a depth interviews with microtunneling experts on the current risk level problems of microtunneling projects installation.

Research Objectives

The main objective of this research is to understand and quantify the risk levels of microtunneling project problems to facilitate, enhance and model risk assessment. The objectives can be broken down into the following sub-objectives:

- Analyze and identify the qualitative risk level factor of microtunneling projects.
- Determine the significant factors that highly contribute to the risk level prediction of microtunneling projects.
- Rank these factors using the Analytic Hierarchy Process modeling technique.
- Build an assessment model based on these factors.
- Validate the developed model.

Background and Significance

Various assessment modeling tools have been developed by researchers and professionals for underground construction utility projects using general construction risk evaluation methods. Ariaratnam (2007) studied the risks involved in the Horizontal Directional Drilling (HDD) and the Open Cut (OC) excavation. The study utilized the Total Risk Index Model (TRI) to calculate the risk value for underground urban utility projects based on the results of a questionnaire survey sent to users and specialists. The model helped calculate the risk value in less time, though it is based on questionnaire results that may vary in the future (Ariaratnam et al. 2007).

Ma et al. (2010) developed a model to quantify the risk of Maxi HDD projects utilizing Fuzzy Comprehensive Evaluation Method (FCEM) and Analytical Hierarchy Process (AHP). FCEM is utilized in complicated projects; however, it provides risk evaluation theoretically instead of mathematically (Ma et al. 2010).

Gierczak (2014) focused on developing a model used for evaluating the safety risk of Mini, Mid, Maxi HDD projects based on Fuzzy Fault Tree Analysis (FFTA). The model is designed for any type of construction practice, but it consumes time due to its use of complex calculations (Gierczak 2014).

Hyun (2015) developed a risk assessment methodology model for underground construction projects based on a fuzzy concept coded for subway projects. The methodology evaluates the factors affecting the risk of a probabilistic analysis module, but the software focuses on subway projects only (Hyun et al. 2015).

Moganti (2016) developed a hierarchical safety risk assessment framework for investigating the safety risks of HDD projects. The model focused on the factors and characteristics of projects presented in two case studies. However, the model needs to be further investigated and extensively evaluated using more real world case studies to be considered as an efficient practice tool (Moganti 2016).

Most of the previous literature developed tools to enhance the decision support system of underground construction. These studies, however, overlooked other factors affecting the risks of microtunneling installation projects. Therefore, understanding the relative importance of each factor is essential to model and predict risk level assessment models used in the installation of microtunneling projects. In this study, a questionnaire was sent to microtunneling-industry experts asking for their opinions about the risk levels that affect microtunneling installation as

well as the importance and significance of these risk levels. The questionnaire analysis resulted in twelve factors as shown in Table 1.

Table 1: Risk level problems factors from questionnaire

Research Methodology

This paper presents the analysis of the qualitative factors that resulted from the questionnaire's responses and the literature. Clustering analysis technique and Analytical Hierarchy Process (AHP) are used to assess the effect of the twelve factors and to incorporate them into a risk level prediction model.

Figure 1 shows the flow chart of detailed work tasks involved in this study to achieve the objectives of this research. The proposed framework consists of five main sections. It begins with a comprehensive literature review followed by data collection. Data collection is conducted by a pilot survey to determine the most remarkable factors, which affect the risk level problems of microtunneling process installation. The survey is conducted based on the experts' opinion of contractors, engineers and manufacturers in the microtunneling industry. To classify the data into homogenous groups, clustering analysis techniques are utilized to identify a group of cases based on the similarity of the variables in these groups. In the clustering analysis technique, the hierarchical method is performed first to define the number of clusters, then the K-means cluster analysis is used to form the clusters. An AHP model is utilized to assess risk level prediction

problems. After developing the AHP model, a validation technique is conducted to check the robustness and the capability of the developed model. The last section includes the conclusion and future results.

Figure 1 Research Methodology

Data Collection

A questionnaire was prepared and conducted by phone to assess the effect of the risk level problem factors on the microtunneling projects' installation. The data were obtained from twenty four experts with almost 20 years of experience in the area of microtunneling projects. The experts were asked to mention and rank the effect a number of factors had on the prediction of risk levels in microtunneling projects. The data results were based on 12 factors. The questionnaire asked the respondents to rate the importance of variables using a 1-5 scale. Because Saaty (1980) recommended a fuzzy scale of 1-10, the rating of each factor was converted from a 1-5 scale to a 1-10 scale using proportional percentages as shown in Table 2.

Table 2: Scale conversion

Background of Cluster Analysis

Clustering is a multivariate learning method that aims to sort a sample of subjects/objects into a number of different subgroups/clusters based on similarity (Jain et al. 1999). The aim of cluster analysis is to classify the data set based on the assumption that the sets belonging to the same clusters are as similar as possible (Elwakil 2011). In addition, cluster analysis is used to identify groups of cases if the grouping is not previously known. Cluster analysis can be carried out using a number of different methods. The methods can be classified as follows:

- Hierarchical method, which is the most common method, consists of two sub methods as shown below.
 - Agglomerative methods: start from n clusters, to get to one cluster.
 - Divisive methods: start from one cluster, to get to n cluster.
- Non-hierarchical ways referred to as the K-means clustering method is a methodology used to quickly cluster large knowledge sets, which usually takes a short amount of time to reason with the most popular class-conscious cluster analysis.
- Two-step cluster analysis takes a while to compute with the preferred hierarchical cluster analysis.

Background of Analytic Hierarchy Process

Analytic Hierarchy Process is a mathematical process that inputs the subjective and personal preferences of individuals to produce a decision (Saaty 1999). Furthermore, the hierarchical structure of system functions and the relative impacts of its elements are the two main components of AHP (Saaty 1980). The AHP hierarchies are based on the human process of

clustering any problem such that the interaction of the components of the clusters' impact on the final decision can be studied (Saito and Sinha 1989).

Clustering can be performed through several steps. First, a deeper understanding of the components of a hierarchical structure and their independence should be considered. Then, mathematical matrix theory should be used to evaluate the relative contributions of the elements in that level toward the element of the upper level (Saaty 1980). The AHP uses eigen values to evaluate this relative contribution by a means of pair wise comparisons. Performing the pair wise comparison requires a scale to represent the qualitative preference of the decision-makers. This scale also reflects the relative weights among the different variables. Saaty (1980) suggested a qualitative scale ranging from 1-9 because it corresponds with the human ability to measure subjective factors.

Clustering Data Analysis

The main goal of using cluster analysis is to classify the data sets into groups that are relatively homogeneous in characteristics on the basis of a defined set of variables. These groups are called clusters. SPSS definition is "a sophisticated piece of software used by social scientists and other professionals for statistical analysis" (Coakes and Steed 2009). SPSS offers three methods for cluster analysis: Hierarchical Cluster, K-Means Cluster, and Two-Step Cluster. In our research, using SPSS clustering techniques is efficient in quickly grouping our data sets into clusters. This approach first performs the hierarchical method to define the number of clusters then uses the K-means cluster analysis to form the clusters. The method is broken down into smaller steps as follows:

1- Hierarchical Cluster Analysis

The hierarchical cluster analysis follows three basic steps (“IBM Knowledge Center - Hierarchical Cluster Analysis,” 2013):

- Calculate the distances. To select a distance measure, we chose square Euclidean distance. The Euclidean distance function measures the “as-the-crow-flies” distance. The formula for this distance between a point X (X1, X2, etc.) and a point Y (Y1, Y2, etc.) is:

$$d = \sqrt{\sum_{i=1}^n (Xi - Yj)^2} \tag{4}$$

Where d: distance between cases i and j.

- Link the clusters. Apply Ward’s methods to the principal components score. Compute sum of squared distances within clusters. Aggregate clusters with the minimum increase in the overall sum of squares.
- Choose a solution by selecting the right number of clusters. Check the agglomeration schedule as shown in Table 3.

Table 3: Agglomeration schedule shows the step of elbow stage

Determine the number of clusters. Apply the elbow rule: identify the step where the “distance coefficients” make a bigger jump. After performing the equation, we found that the data can be classified into four clusters.

The number of clusters = the number of cases- the step of elbow stage

$$= 24 - 20 = 4 \text{ clusters.}$$

2- K-Means Cluster Analysis

After determining the number of clusters from the hierarchical clustering analysis, apply the K-Means method:

- Repeat the analysis using the K-Means technique.
- Set 4 as the number of clusters.
- Save cluster membership for each case as shown in Table 4.

We convert the four clusters into a fuzzy scale that ranges from Very low to High risk assessment level as shown in Table 5.

Table 4: Final output shows cluster membership

Table 5: Classifying the clusters into six clusters based on a fuzzy scale

AHP Application to Risk Level Prediction Model

To rate the qualitative factors in microtunneling projects, the AHP is developed based on the risk level factors. The model passes through several steps to apply the AHP technology as shown below.

1- Setting up the hierarchy

The AHP technique is used in calculating the W_i for every qualitative variable (Dias and Ioannou 1995; Saito and Sinha 1989). Defining the problem and developing the hierarchy is the first step in the AHP model. The problem is represented accurately by breaking it down into its components. The goal, criteria/factors, and the alternatives are the three main levels of the hierarchy. The first level is the main goal of the decision-maker. The second level shows various criteria/factors that remarkably contribute to the main goal in the first level. The last and third level of the hierarchy is the alternatives. The AHP model evaluates these alternatives in respect to the criteria in the second level. Shown in Figure 2, the risk level assessment model consists of three main levels. Level 0 is the risk level assessment problem. Level 1 consists of the twelve qualitative factors. Level 2 represents the final output component risk level ranging from 0-100.

Figure 2 Hierarchy of the developed model

2- Pair-wise comparison

The pair-wise comparison matrices that were applied between the qualitative variables, which is a reciprocal matrix, were constructed as shown in Table 6. The matrix has a value of “1” in the main diagonal, and elements below the main diagonal are reciprocal to the elements above it ($a_{ji} = 1/a_{ij}$). The value of each a_{ij} is calculated from the questionnaire responses. Dividing the effect rank of variable i over the effect rank of variable j gives the matrix element a_{ij} . The

number of elements in a matrix $n \times n$ elements are $n(n-1)/2$ (Shappered and Cartwright 2000).

Therefore, the matrix can be expressed as follows:

$$\begin{bmatrix} 1 & x & y \\ \frac{1}{x} & 1 & z \\ \frac{1}{y} & \frac{1}{z} & 1 \end{bmatrix}$$

Table 6: Risk level factors' pair-wise comparison matrix

3- Assigning Priorities

To attain the weight of each factor, the AHP methodology is applied to these factors.

Consequently, all pairwise comparison matrices, for main factors and subfactors, are filled with numerical values, which represents the importance of each factor against the others.

4- Establish Priority Vector

In this step, the authors use Saaty's methodology to calculate the eigenvector or weighting vector (W_i) for each pairwise matrix (Saaty 1999). The weight of each factor demonstrates this factor among the other factors; however, the total value of these weights for each matrix is equal to one.

5- Consistency Analysis

In this step, we verified if the consistency of a pair-wise comparison matrix that results in the factors' weights can be considered. If the matrix is consistent, the weights are accepted.

Otherwise, we have to return the weights to the experts to reassess their evaluation. The consistency index (CI) and consistency ratio (CR) has been calculated as follows (Saaty 1999):

$$CI = (\lambda_{\max} - m) / (m - 1) \tag{5}$$

$$CR = CI / RI \tag{6}$$

Where:

CI = the matrix consistency index. m = matrix size.

$\lambda_{\max}$ = the maximum eigenvalue.

RI = random index (it has a value related to the matrix size) (Saaty 1996)

The values of the CI of the main matrix is approximately zero; and consequently CR value is zero, which is less than 0.10. Overall, the matrix is consistent and verified.

6- Trenchless Technology Risk Level Assessment Model

The last step of the AHP assessment model is to obtain the risk level assessment value using Equation 7 on a scale from 0-100. The equation combines the different priority matrices with the efficiency rating score which results in generating a risk level assessment value by a summation of the results. According to this procedure, the risk level value can be calculated using the following formula:

$$QF = \sum_{i=1}^n W_i * V_i \tag{7}$$

Where:

W_i : Relative weight for variable number i

V_i : Worth value for variable number i

n : Number of qualitative variables

Results

The previous steps were followed to analyze the responses of the questionnaire for the qualitative factors. In the AHP model, the factors were ranked according to importance as shown in Figure 3. We found that the most effective factor in risk level problems is acts of God followed by water level change, M/T breakdown, pipeline leakage, injuries, and mislead of laser. On the other hand, insufficient torque, ground settlement, schedule failure, soil condition change, unforeseen conditions, and obstacles were the lowest ranked factors on the risk level factors in the current study. The resulting weight after multiplying the eigenvector and the worth value of each factor is shown in Table 7. This value can be interpreted as a multiplier to the risk assessment prediction models of microtunneling projects to consider the combined effect of the risk condition levels.

Figure 3. Total combination weights of qualitative factors' effect on the risk level problems

prediction of microtunneling projects

Table 7: The combined results of the developed model

Validation of AHP model

The validation process is to guarantee that the developed models best fit the available data. To validate the AHP model, we divided the collected data into two data sets: 80% of data for building the model, while 20% is for validation. We selected the validation data set (20%) randomly and kept it as we developed the AHP model. Then we compared the predicted results with the real values of the validation data set, as shown in Table 8. Equations 8 and 9 (Zayed and Halpin 2005) were used to validate the developed AHP model as follows:

$$(AIP) = \sum_{i=1}^n \{1 - I(E_i / C_i) I\} * 100/n \tag{8}$$

$$(AVP) = 100 - AIP \tag{9}$$

Where AIP is the Average Invalidity Percent, AVP is the Average Validity Percent, E_i is the i^{th} predicted value, C_i is the i^{th} actual value, and n is the number of observations.

Table 8: Validation results of the developed model

The AVP and AIP values for productivity index model using AHP showed that:

AIP = 10.41% and AVP = 89.59%. These results indicated that the obtained results were satisfactory and acceptable, as shown in Figure 4.

Figure 4: AHP risk level assessment model validation shows actual cluster membership output versus predicted output percentage

Conclusion

This research proposed an assessment model based on the risk level problems that affect the installation of microtunneling projects. The model was developed by utilizing the cluster analysis technique and AHP to assist the contractors in the bidding and operation phases of microtunneling projects with higher efficiency and accuracy. This study proposed that the qualitative factors of risk levels affecting the installation of microtunneling projects can be evaluated using the AHP technique. Furthermore, the risk level assessment was calculated based on the responses from a questionnaire administered to microtunneling-industry experts. The data sets were then classified into homogenous groups using the cluster analysis technique. The SPSS clustering technique was utilized to cluster the data through hierarchical clustering techniques and the K-Means clustering analysis, which resulted in a 4 cluster membership output.

The AHP model resulted in ranking the factors from the highest to the lowest efficiency on the risk level assessment, which shows that acts of God, water level change, M/T breakdown, pipeline leakage, injuries, and mislead of laser are the highest effective factors, while insufficient torque, ground settlement, schedule failure, soil condition change, unforeseen conditions, and obstacles are the lowest ranked factors of the risk level factors.

Overall, the AHP model was validated with 89.59% Average Validity Percent (AVP), which is considered a satisfactory result. Consequently, the PI model is valid and accepted for practice use in the real world.

387

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457 **Tables**

458 Table 1: Risk level problems factors from questionnaire

Factor	#	Explanation
(1)	(2)	(3)
Obstacles	1	A thing that blocks one’s way or prevents progress
Soil Condition Change	2	The condition of soil is changed quickly based on environmental factors such as changes in moisture.
Unforeseen Condition	3	Unexpected circumstance or situation that affects the final price and/or completion time of a project.
Mislead of Laser	4	Miss alignment due to the need of calibration
M/T Breakdown	5	Using the appropriate machine (slurry or EPB)
Water Level Change	6	Groundwater level change due to natural phenomena and others are caused by man’s activities.
Insufficient Torque	7	Insufficient twisting force
Acts of God	8	An instance of uncontrollable natural forces in operation
Pipeline Leakage	9	Pipeline leak detection is used to determine if and in some cases where a leak has occurred in systems which contain liquids and gases.
Injuries	10	An instance of being injured

Schedule Failure	An excessively aggressive schedule results in
11	mistakes being made from which the project never
	recovers.

Ground Settlement	Differential or uneven settlement occurs when the
12	soil beneath a structure cannot bear the weights
	imposed.

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Table 2: Scale conversion

Variables	Original scale	Fuzzy scale	Worth Value (V_i)
(1)	(2)	(3)	(4)
Obstacles	2.1	4.2	0.42
Soil Condition Change	2.6	5.2	0.52
Unforeseen Condition	2.2	4.4	0.44
Mislead of Laser	3.25	6.5	0.65
M/T Breakdown	2.45	6.9	0.69
Water Level Change	3.65	7.3	0.73
Insufficient Torque	3.2	6.4	0.64
Acts of God	3.7	7.4	0.74
Pipeline Leakage	3.45	6.9	0.69
Injuries	3.4	6.8	0.68
Schedule Failure	3	6	0.6
Ground Settlement	3.2	6.4	0.64

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Table 3: Agglomeration schedule shows the step of elbow stage

Agglomeration Schedule						
Stage	Cluster		Coefficients	Stage		Next
	Cluster 1	Cluster 2		Cluster 1	Cluster 2	
1	24	25	0	0	0	2
2	5	24	0	0	1	5
3	21	22	1.5	0	0	18
4	16	20	5.542	0	0	6
5	4	5	10.042	0	2	10
6	16	18	15.995	4	0	9
7	1	6	22.495	0	0	16
8	10	11	29.495	0	0	19
9	14	16	36.857	0	6	12
10	4	15	44.757	5	0	11
11	4	8	52.691	10	0	15
12	13	14	62.536	0	9	17
13	17	23	73.536	0	0	19
14	3	7	84.536	0	0	20
15	4	12	96.488	11	0	20
16	1	19	108.655	7	0	22
17	9	13	122.308	0	12	18
18	9	21	138.27	17	3	22
19	10	17	154.77	8	13	21
20	3	4	176.818	14	15	21
21	3	10	214.83	20	19	23
22	1	9	254.12	16	18	23
23	1	3	354.126	22	21	0

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466 Table 4: Final output shows cluster membership
467

RISK LEVEL OF PROBLEMS												
Obstacles	Soil Cond. Change	Unforeseen Cond.	Mislead of Laser	M/T Breakdown	Water level Change	Insufficient Torque	Acts of God	Pipeline Leakage	Injuries	Schedule Failure	Ground Settlement	Output (cluster membership)
4	4	4	3	3	1	3	3	3	1	2	2	1
1	1	1	3	3	5	4	4	4	4		4	4
2	1	2	3	5	4	5	3	4	2	3	5	4
1	2	1	5	4	5	4	5	4	5	3	3	4
1	3	2	4	4	5	3	4	4	5	4	3	4
3	3	5	3	4	2	3	1	1	1	2	2	1
2	2	1	4	4	4	3	1	4	5	4	5	4
2	3	2	5	4	4	3	5	5	5	5	5	4
3	4	3	1	1	3	1	5	4	3	3	3	2
5	3	4	4	5	4	5	4	4	4	4	3	3
3	2	2	3	5	5	4	5	4	4	4	2	3
1	1	1	3	3	3	3	5	3	5	4	3	4
1	1	1	1	1	3	3	3	3	3	1	3	2
1	2	2	1	3	5	2	3	4	3	3	2	2
2	4	3	5	5	5	4	4	3	4	3	4	3
2	3	2	3	4	4	3	4	4	4	3	3	4
4	4	2	5	4	2	3	4	3	3	3	4	1
1	3	1	3	2	4	2	4	3	3	2	4	2
1	3	2	4	3	2	3	4	2	1	2	2	1
2	3	3	2	2	3	3	3	3	3	2	2	2

3	2	2	3	3	3	2	2	4	3	2	1	2
3	2	1	3	3	3	1	3	4	3	2	1	2
5	5	5	3	4	4	3	5	3	3	4	5	3
1	3	2	4	4	5	3	4	4	5	4	3	4
1	3	2	4	4	5	3	4	4	5	4	3	4

468

469

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470 Table 5: Classifying the clusters into six clusters based on a fuzzy scale

Cluster Membership	Fuzzy Scale	Assessment Condition
1	100	Very low
2	83.3	Low
3	66.67	Medium
4	50.00	High

471

472

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473

Table 6: Risk level factors' pair-wise comparison matrix

	Obstacles	Soil Cond. Change	Unforeseen cond.	Mislead of Laser	M/T Breakdown	Water Level Change	Insufficient Torque	Acts of God	Pipeline Leakage	Injuries	Schedule Failure	Ground Settlement
Obstacles	1.00	0.81	0.95	0.65	0.61	0.58	0.66	0.57	0.61	0.62	0.70	0.66
Soil Cond. Change	1.24	1.00	1.18	0.80	0.75	0.71	0.81	0.70	0.75	0.76	0.87	0.81
Unforeseen cond.	1.05	0.85	1.00	0.68	0.64	0.60	0.69	0.59	0.64	0.65	0.73	0.69
Mislead of Laser	1.55	1.25	1.48	1.00	0.94	0.89	1.02	0.88	0.94	0.96	1.08	1.02
M/T Breakdown	1.64	1.33	1.57	1.06	1.00	0.95	1.08	0.93	1.00	1.01	1.15	1.08
Water Level Change	1.74	1.40	1.66	1.12	1.06	1.00	1.14	0.99	1.06	1.07	1.22	1.14
Insufficient Torque	1.52	1.23	1.45	0.98	0.93	0.88	1.00	0.86	0.93	0.94	1.07	1.00
Acts of God	1.76	1.42	1.68	1.14	1.07	1.01	1.16	1.00	1.07	1.09	1.23	1.16
Pipeline Leakage	1.64	1.33	1.57	1.06	1.00	0.95	1.08	0.93	1.00	1.01	1.15	1.08
Injuries	1.62	1.31	1.55	1.05	0.99	0.93	1.06	0.92	0.99	1.00	1.13	1.06
Schedule Failure	1.43	1.15	1.36	0.92	0.87	0.82	0.94	0.81	0.87	0.88	1.00	0.94
Ground Settlement	1.52	1.23	1.45	0.98	0.93	0.88	1.00	0.86	0.93	0.94	1.07	1.00

474

475

Table 7: The combined results of the developed model

Factors	Eigenvector	Worth Value (Vi)	W*Vi
Acts of God	0.099	0.74	0.074
Water Level Change	0.098	0.73	0.072
M/T Breakdown	0.093	0.69	0.064
Pipeline Leakage	0.093	0.69	0.064
Injuries	0.091	0.68	0.062
Mislead of laser	0.087	0.65	0.057
Insufficient Torque	0.086	0.64	0.055
Ground Settlement	0.086	0.64	0.055
Schedule Failure	0.081	0.6	0.048
Soil Condition Change	0.070	0.52	0.036
Unforeseen conditions	0.059	0.44	0.026
Obstacles	0.056	0.42	0.024

480

Table 8: Validation results of the developed model

Cluster Membership Output	Actual Fuzzy Scale of Cluster Membership Output	Predicted Cluster Membership Output	AIP
2.000	50.000	50.493	0.01
2.000	50.000	49.579	0.01
3.000	75.000	80.258	0.07
4.000	100.000	73.176	0.27
4.000	100.000	73.176	0.27
AIP (%)			10.41
AVP (%)			89.59

481

482

List of Figure Captions

Figure 1. Research Methodology

Figure 2. Hierarchy of the developed model

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Figure 3. Total combination weights of qualitative factors' effect on the risk level problems prediction of microtunneling projects

Figure 4. AHP risk level assessment model validation shows actual cluster membership output versus predicted output percentage